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Influence of Curing Age and Mix Composition on Compressive Strength of Volcanic Ash Blended Cement Laterized Concrete

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Abstract: This study investigates the influence of curing age and mix proportions on the compressive strength of volcanic ash (VA) blended cement laterized concrete. A total of 288 cubes of 100mm dimensions were cast and cured in water for 3, 7, 28, 56, 90 and 120 days of hydration with cement replacement by VA and sand replacement by laterite both ranging from 0 to 30% respectively while a control mix of 28-day target strength of 25N/mm^2 (using British Method) was adopted. The results show that the compressive strength of the VA-blended cement laterized concrete increased with the increase in curing age but decreased as the VA and laterite (LAT) contents increased. The optimum replacement level was 20%LAT/20%VA. At this level the compressive strength increased with curing age at a decreasing rate beyond 28 days. The target compressive strength of 25N/mm^2 was achieved for this mixture at 90 days of curing. VA content and curing age was noted to have significant effect ($\alpha \leq 0.5$) on the compressive strength of the VA-blended cement laterized concrete.

Keywords: Volcanic ash (VA), laterized concrete, compressive strength, curing age, mix proportions.

Introduction

Basic conventional building materials, like cement and sand, are becoming increasingly expensive to obtain because of high cost incurred in cement production, sand excavation process, pre-treatment and transportation. A 50kg bag of cement, which sold for NGN 280 and NGN 480 in December 1994 and April 1995 respectively [1], was sold for NGN 1850 as of September, 2008 and now NGN 2900 in April, 2011 in Minna market, Nigeria. Umoh [2] reported that in spite of the large cement factories in Nigeria, the yearly supply does not match the demand for cement, due to most of the factories do not produce at full installed capacity. The importation of cement is economically inadvisable. The difference between demand and supply invariably has an effect on the cost of cement. The ever upward rise in cost of basic building materials (i.e. cement and sand) in Nigeria poses great threat to the realisation of "affordable housing for all" agenda of our Governments.

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This situation can be improved if the potentials of laterite as a substitute to sand is fully exploited or popularised in addition to the advantage of its wider geographical spread and local availability on nearly every building site [3].

The provision of housing is governed by the need for shelter. According to Fitch and Branch [4], the need for shelter must be met by materials that the environment can afford. Such materials must therefore be widely and readily available, appropriate to the environmental demands, thermally efficient and socially acceptable [5]. Besides, the building system derived from such materials must allow participation from the community and thereby improving the cash economy of that community. This is what Adegoke and Ajayi [6] referred to as appropriate technology. Examples of such locally available building materials that fit into these descriptions are cement replacement materials such as rice husk ash, corncob ash, sawdust ash, volcanic ash and conventional sand replacement materials such as erosion sand and laterite. This paper presents influence of curing age and mix proportion on the compressive strength of VA-blended cement laterized concrete, as part of an ongoing research on the use of volcanic ash as a pozzolana in laterized concrete with experimental design for up to 120days of hydration in consonance with previous works such as Matawal [7], Neville [8] and Neville & Brooks [9] respectively. An earlier work by Olawuyi and Olusola [10] reported the outcome of an initial study up to 28-days hydration period.

Literature Review

The ever upward trend in the cost of basic conventional materials like cement and sand has geared concentration of research efforts towards either purely partial or total replacement of ordinary Portland cement (OPC) in concrete on one hand, or the replacement of sand with laterite on the other. Job [11] reported the efforts made by researchers like Popovics [12], Smith [13], Talero [14] and Neville [8] to substitute cement with locally available materials called pozzolanas. "Pozzolana" is used to describe naturally occurring and artificially siliceous or siliceous and aluminous materials, which in themselves possess little or no cementitious value but will, in finely divided form and in presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compound possessing cementitious properties [9, 15, 16, and 17]. Matawal [7] stated that recent researches in Nigeria and abroad have shown that pozzolanas can produce concrete with close characteristics as normal concrete at ages beyond 28 days.

Volcanic ash referred to as "original pozzolan" [9], is a finely fragmented magma or pulverised volcanic rock, measuring less than 2mm in diameter, which is emptied from the vent of a volcano in either a molten or solid state. The most common state of ash is vitric (glass like), which contains glassy particles formed by gas bubble busting through liquid magma [18]. It comprises small jagged piece of rock minerals and volcanic glass that was erupted by a volcano [19].

Volcanic ash is opined not to be a product of combustion like soft fluffy material created by burning wood, leaves or paper. It is hard, does not dissolve in water and is extremely abrasive, mildly corrosive and conducts electricity when wet. In the opinion of Shoji, et al., [19], the average grain size of rock fragment and volcanic ash erupted from an exploding volcanic vent varies greatly among different eruption. Heavier and large size rock fragment typically fall back to the ground or close to the volcano while smaller and lighter fragments are blown farther from the volcano by wind.

It has been for millennia that the mixture of volcanic ash or pulverized tuff (siliceous), with lime produces hydraulic cement. An examination of ancient Greek and Roman structures provide sample evidence of the effectiveness and durability of this cement. The lining to a cistern in Kamiros, Rhodes (230 km East of Santorini) dating from the 6th or 7th century BC is still in existence. Pozzolanic natural cement was for millennia the only available material for lining cisterns and aqueducts and binding the brick and stone of water–front structure and monumental buildings.

Volcanic ash is still used in various countries like Greece, Italy, Germany, Mexico and China, because it reduces cost and improves quality and durability of concrete. When volcanic ash develops internal cementation, it is transformed into a soft rock called Tuff. In spite of its inferior qualities when compared with other stones (lower strength and resistance to erosion), Tuff is often quarried and used as building stone.

Abundant deposit of Basalt formations (the parent material of volcanic ash) in Nigeria as reported in literature [20, 21], thereby informed this study on the potential of volcanic ash as a useful component in laterized concrete.

Laterite or laterized concrete on the other hand has attracted the attention of many authors and researchers. Gidigasu [22] as cited in Olusola [5] defined laterite as a term used to describe all the reddish residual and non-residual tropically weathered soils, which generally form a chain of materials ranging from decomposed rock through clay to sesquioxide (Al_2O_3 + Fe_2O_3)-rich crusts, generally known as carapace. Laterite, either in raw form or improved form is commonly used both in rural and urban areas for housing construction in form of masonry units. The Federal low-cost housing scheme at satellite town, Ojo, Lagos, Nigeria is built of stabilized laterite blocks. So also are low-cost housing schemes in some States like Kebbi, Ekiti and others in Nigeria built with hydra-form (i.e. interlocking stabilized laterite) blocks [3]. However, it has not been widely utilized to an equal level as sandcrete blocks and concrete, especially for structural works [23]. The reasons for this had been given as uncertainties as to their reliability, lack of knowledge of their physical properties and strength characteristics prior to use, inadequate knowledge of the actual performance of structures made from it under varying climatic condition and problems of quality control [23, 24]. The public believed that for laterite to be used on a wider scale, it should be improved at the technical level. Research investigations [3, 5, 10, 20, 23, and 24] has shown that stabilized laterite (laterite mixed with a certain quantity of cement $\leq 10\%$ by mass) can be advantageously used for the production of masonry units and that laterite holds promise as a partial replacement for sand in concrete constructions, both structural and non-structural.

Laterized concrete is defined as concrete in which stable laterite fines replace sand wholly or partially; whole replacement is also referred to as terracrete [5]. Neville [16] reported that laterite when used to wholly replace sand in concrete can rarely produce concrete stronger than 10 MPa (10 N/mm^2). Report of studies by Osunade [25], Ata [26] and Olusola [5] has proved this is not true; they submitted that laterite can produce concrete of much higher grades. An earlier report of initial work on this study [10] presented volcanic ash showing 20%LAT/20%VA as having 67% pozzolanicity index at 28-day.

Materials and Methods

The volcanic ash used was obtained from Kerang in Mangu Local Government Area of Plateau State in Nigeria as a solid mass. This was grinded and sieved with a 75 µm sieve at the Civil Engineering Laboratory of the Federal University of Technology, Minna, Nigeria. The sample was then subjected to Chemical Analysis for determination of the oxide contents in Lafarge Cement (formerly West African Portland Cement Company–WAPCO), Sagamu Works Department. The analysis was carried out using X-Ray Fluorescent Analyser called Total Cement Analyser (Model ARL 9900 XP), connected directly to a computer system. The result of the chemical analysis is as presented in Table1, reflecting a Silicon Dioxide (SiO_2) content of 41.13% which is greater than BS EN 197-1(2000) [27] minimum requirement of 25.0% and a total Silicon Dioxide, Iron Oxide, and Aluminium Oxide (SiO_2 + Fe_2O_3+Al_2O_3) content of 70.99% which is slightly higher than the values gotten in earlier studies 63.74% by Lar and Tsalha [21] and 67.14% by Hassan [28] as stated in the earlier study [10]. This value meets the minimum total SiO_2+Fe_2O_3+Al2O3 specified by the ASTM C618-2008 [17].

The SO_3 content is 0.13% which is below the maximum value of 4.0% as specified for Class N pozzolan to which it belongs; in ASTM C618-2008 [17].

Table 1. Result of Chemical Analysis of the Volcanic Ash Sample

Elements	% Composition by mass
SiO_2	41.13
Al_2O_3	18.36
Fe_2O_3	11.5
CaO	6.57
MgO	4.24
SO_3	0.13
K_2O	1.12
Na_2O	1.29
Mn_2O_3	0.29
P_2O_5	1.00
TiO_2	3.56
Cl-	0.00
SUM	88.92
LSF	4.64
SR	1.38
AR	1.60
LOI	8.30
SiO_2+Al_2O_3+Fe_2O_3	70.99

The loss on ignition (8.60) though higher than the value (2.71) gotten in earlier study by Hassan [28], is also below the maximum allowable (10.0) specified. The volcanic ash sample is thereby noted to have Lime Saturation Factor (LSF) of 4.64; Silica Ratio (SR) or Silica-Sesquioxides Ratio of 1.38 and Aluminium Ratio (AR) of 1.60.

Table 2 shows the specific gravity of the VA sample as 2.60, which is lower than values gotten in earlier studies; 3.04 by Olawuyi and Olusola [10] and 3.05 by Hassan [28]. The cement sample has a specific gravity of 3.21 a value similar to 3.15 as posited by Neville [16].

The fineness modulus of sand (2.6) indicated a medium grading, while laterite reflected a coarse grading (3.2). The coefficient of uniformity, C_u, for both sand and laterite was greater than 6.0, while coefficient of curvature, C_c, fell between 1.0 and 3.0, this implied both materials used as fine aggregate were well graded and are therefore very suitable for making good concrete. The values of C_u (1.34) and C_c (1.15) for the granite implied a uniformly graded coarse aggregate, but this is still within the limits required for suitable coarse aggregate for good concrete. All the aggregates thereby conformed to the British Standard Specification [29, 30]. The cement type used was Dangote Portland cement produced in Obajana factory, Kogi State, Nigeria and conformed to BS EN 197-2000 [27].

The laterite sample was noted to have a liquid limit value of 36.79, plastic limit of 26.11 and plastic index of 10.68, all giving Atterberg limits conforming to the range specified by the findings of Abidoye [31]. The oxide composition determined via chemical analysis of the laterite sample at WAPCO Sagamu works department, using X-Ray Fluorescent Analyser called Total Cement Analyser (Model ARL 9900 XP) reflects a Silica-Sesquioxide (S-S) ratio of 0.97 implying a true laterite.

Table 2. Summary of Physical Properties of Constituent Materials

Item	Cement	VA	Sand	Laterite	Granite
Specific Gravity	3.21	2.60	2.59	2.68	2.66
Loose Bulk Density (Kg/m^3)	-	-	-	1263	1452
Compacted Bulk Density (Kg/m^3)	-	-	-	1907	1580
Moisture Content (%)	-	-	3.67	14.15	-
Sieve Analysis					
Fineness Modulus	-	-	2.60	3.20	-
D60	-	-	0.95	1.45	16.15
D30	-	-	0.36	0.58	15.00
D10	-	-	0.13	6.60	12.06
C_u	-	-	7.30	6.60	1.34
C_c	-	-	1.05	1.05	1.15

The compressive strength was determined using 100 mm concrete cubes. A total of 288 cubes were cast for the four levels (0%, 10%, 20%, and 30%) of volcanic ash replacements of cement, four laterite replacement levels (0%, 10%, 20%, and 30%) of sand and six curing durations (3, 7, 28, 56, 90, and 120 days). The control mixture was proportioned for a target concrete strength of 25 N/mm² and had a cementitious material content of 290 kg/m³, fine aggregate content of 530 kg/m³, coarse aggregate content of 1465 kg/m³, and a water cementitious materials ratio of 0.65 giving a free water content of 190 kg/m³. The cement and sand replacement by VA and LAT respectively were thereby computed for by mass as required.

The 100 mm cube moulds were fabricated in a welding shop in Minna using a 4 mm thick grade 55 steel sheets ensuring they conform to BS EN 12390 – 1:2000 [32] specifications. The moulds were thoroughly cleaned and coated with used engine oil before casting to ensure easy demoulding and smooth surface finish. The wet mixture was cast into moulds immediately after mixing with hand trowel. The moulds were filled in two layers of 50 mm each, compacted using the compaction rod (25 mm diameter steel rod), the minimum of 25 strokes uniformly distributed over its surface during casting as stipulated by the requirements of BS EN 12390 – 2, and 3:2000 [33,34]. The top of each mould was smoothened and levelled and the outside surfaces cleaned. The mould and their contents were kept in the curing room at temperature of 27 ± 5^{0}C and relative humidity not less than 90% for 24 hours. Demoulding of cubes took place after 24 hours and the specimens were transferred into a water bath maintained at 27± 5^{0}C in the curing room. Compressive strength was determined at curing age 3, 7, 28, 56, 90, and 120 days in-line with the code specification.

Results and Discussion

The mean compressive strength (i.e. average of the triplicate) of VA-blended cement laterized concrete and the effects of curing age and percentage replacements of cement with volcanic ash is presented in Table 3, while Figures 1 to 4 show graphically the effect of this variables at the various levels of laterite content (0%, 10%, 20%, and 30% respectively).

The compressive strength generally increased with curing age and decreased with increased percentage of volcanic ash in the mix. Up to the 20%Lat/20%VA replacements, the VA-blended cement laterized concrete has a minimum of 70% strength of the control at the 28 day. At ages beyond 28 days the VA-blended cement laterized concrete shows strengths comparative to that of the control. Specifically at the 120 days, the lowest strength was 23.69 N/mm² (91.22% of 28 day of control); this is in consonance with the code's (ASTM C618:2008) [17] expectation of pozzolanic cement and in line with Matawal [7] postulations. The 28 day strength of 20%Lat/20%VA sample (70.91%); a slight improvement on the result of the earlier initial study of 67% [10] can be due to the improved chemical properties of this particular VA sample. This though is a bit lower than the code requirement for pozzolanicity test; this mix can be seen as the limit of replacement with the hope that the 75% requirement can be met with little treatment on the volcanic ash to improve its chemical composition.

Table 3. Summary of Compressive Strength of VA-blended Cement Laterized Concrete

Specimen	Lat. Cont.	VA Cont.	Compressive Strength (N/mm²)					
No.	(%)	(%)	3 Days	7 Days	28 Days	56 Days	90 Days	120 Days
A	0	0	11.02 (42.43)	18.5 (71.24)	25.97 (100.00)	27.44 (105.66)	28.47 (109.63)	29.14 (112.21)
B	0	10	8.61 (33.15)	12.39 (47.71)	21.97 (84.60)	21.97 (84.60)	25.14 (96.80)	26.34 (101.42)
C	0	20	7.38 (28.42)	10.79 (41.55)	20.07 (77.28)	21.74 (83.71)	22.19 (85.44)	22.57 (86.91)
D	0	30	6.45 (24.84)	9.82 (37.81)	18.96 (73.43)	18.96 (73.01)	20.97 (80.75)	22.02 (84.79)
E	10	0	8.67 (33.380	11.55 (44.47)	21.55 (82.98)	22.21 (85.52)	26.78 (103.12)	27.33 (105.24)
F	10	10	8.03 (30.92)	9.77 (37.62)	19.07 (73.43)	21.67 (83.44)	24.05 (92.61)	25.09 (96.61)
G	10	20	7.04 (27.11)	8.62 (33.19)	18.38 (70.77)	20.98 (80.79)	23.52 (90.57)	23.65 (91.07)
H	10	30	5.11 (19.68)	6.80 (26.18)	18.2 (70.08)	19.63 (75.59)	20.97 (80.75)	21.07 (81.13)
I	20	0	8.89 (34.23)	9.97 (38.390	21.06 (81.09)	24.19 (93.15)	26.69 (102.77)	27.06 (104.20)
J	20	10	8.52 (32.81))	9.49 (36.54)	19.26 (74.16)	21.76 (83.79)	24.16 (93.03)	24.96 (96.11)
K	20	20	7.24 (27.88))	7.65 (29.46)	18.4 (70.85)	21.53 (82.90)	24.43 (94.07)	24.52 (94.42)
L	20	30	5.19 (19.98)	6.98 (26.88)	17.72 (68.23)	20.75 (79.90)	21.75 (83.75)	22.95 (88.37)
M	30	0	8.46 (32.58)	9.74 (37.50)	20.59 (79.28)	22.93 (88.29)	25.26 (97.27)	26.19 (100.82)
N	30	10	7.13 (27.45)	8.24 (31.73)	18.9 (72.78)	21.97 (84.60)	25.00 (96.26)	25.89 (99.69)
O	30	20	6.64 (25.570	7.63 (29.38)	18.03 (69.43)	20.9 (80.48)	23.66 (91.11)	23.77 (91.53)
P	30	30	5.02 (19.33)	6.28 (24.18)	17.46 (67.23)	20.46 (78.78)	23.46 (90.34)	23.69 (91.22)

Note: Value in parenthesis refers to percentage of 28day strength of the control (0%Lat/0%VA).

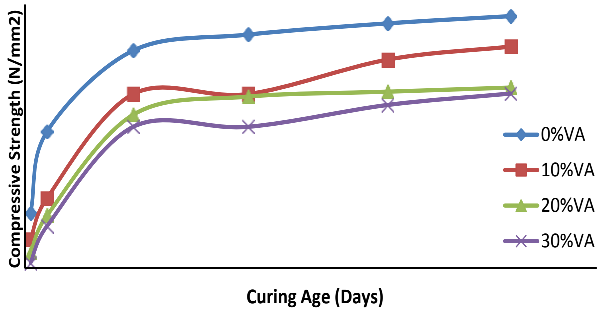

Figure 1. Compressive Strength of VA-blended Cement Laterized Concrete at 0% Laterite

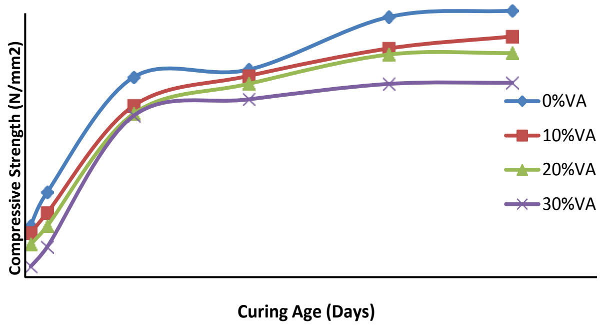

Figure 2. Compressive Strength of VA-blended Cement Laterized Concrete at 10% Laterite.

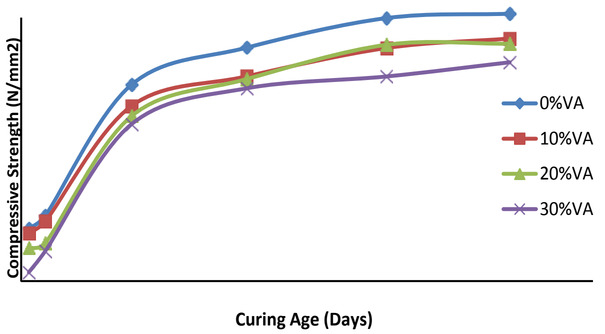

Figure 3. Compressive Strength of VA-blended Cement Laterized Concrete at 20% Laterite.

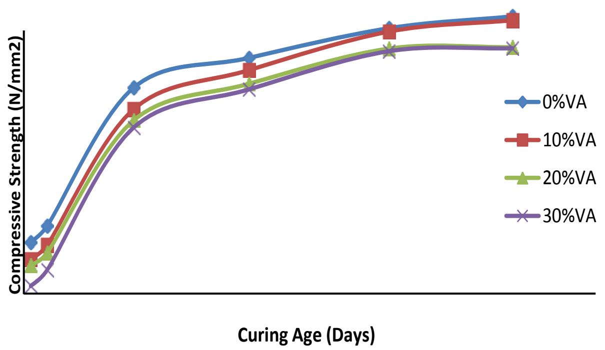

Figure 4. Compressive Strength of VA-blended Cement Laterized Concrete at 30% Laterite

The results as shown in Figures 1 to 4 reflect that the rate of strength development of VA-blended cement laterized concrete was slow at early curing ages but faster at later ages, unlike the strength development of the control (i.e. 0%Lat/0%VA – normal concrete) which accelerates at the initial stage and then decelerates after 28 days. These results corroborate earlier findings on pozzolan cement concrete [27, 35, 36, and 37]. This implies that VA-blended cement laterized concrete is not advisable for use when early strength is required; rather it is mostly applicable for structures requiring long term strength development. Thus, it could be concluded that the strength characteristics of VA-blended cement laterized concrete is a function of the curing age and percentage VA content.

The influence of laterite content, volcanic ash content (i.e. mix proportions) and curing age (called independent variables) on the compressive strength (called dependent variable) was statistically analyzed using Analysis of Variance (ANOVA) and the result is presented as shown in Table 4.

The results of the statistical analysis as shown in the table, indicated that all the independent factors, when considered individually and collectively (two and three factors interactions) had significant effects on the compressive strength of the concrete at 95% confidence level (α = 0.05). This indicates that whenever any of the factors is varied, the compressive strength of the concrete changes and the degree of the variation is proportional to the magnitude of the change. The coefficient of determination (adjusted R-Square value) obtained from the analysis was 0.986 (98.6%). This implies a strong statistical association among the three independent variables and the dependent variable. The independent variables were estimated to account for 98.6% of the variance in the compressive strength of the concrete. The coefficient of correlation (square root of adjusted R-square) was obtained as $R = 0.993$. This shows that a very strong correlation or linear relationship exist between the two sets of variables being considered. A strong correlation is assumed to exist between two variables if $0.5 < r < 1.0$, otherwise the correlation is weak. The statistical analysis revealed that the mean compressive strength for all curing ages' and replacement levels of laterite and volcanic ash curing ages is 17.93 N/ mm^2. The Duncan's multiple range tests (see Tables 5 to 7) revealed that the mean compressive strengths for the various VA content are significantly different; with 0%VA having the highest mean compressive strength of 24.00 N/ mm^2 when other variables are kept constant. When volcanic ash content and curing ages were kept constant and the effect of percent replacement of sand with laterite was statistically investigated using the Duncan's multiple range tests, the result also shows that the mean compressive strengths at the different percent replacement levels are significantly different.

The highest mean compressive strength was 19.12 N/mm^2 for 0% laterite content followed by a mean strength of 17.71 N/mm^2 for 20% replacement of sand with laterite; this implies the 20% laterite content is the optimum level of replacement of sand with laterite in this study. The effect of curing ages on the compressive strength of the VA-blended cement laterized concrete when other variables were kept constant also showed that the mean compressive strength of the curing ages tested (3, 7, 28, 56, 90, and 120 days) are significantly different.

Conclusion

The result presented demonstrate that VA sample has Silica (SiO_2) content of 41.13% and total SiO_2+Fe_2O_3+Al_2O_3 of 70.99%, thereby meeting the minimum requirements of ASTM C618-2008 [17] requirement for pozzolana. The compressive strength of VA-blended cement laterized concrete is lower than that of granite concrete (control 0%LAT/0%VA) at early curing age but improves significantly at later ages and has higher rate of strength gain than the later. The optimum level of replacement from structural load view point is 20%LAT/20%VA at which about 95% of the 28th day strength of the control. This strength value (24.43 N/mm^2 ≈ 25 N/mm^2) for this sample equals the 28-day target strength designed for. The VA-blended cement laterized concrete is hereby recommended for adoption in mass concrete construction, low heat construction and in situation where early strength is not required up to 20% laterite substitution of sand and 20% volcanic ash substitution of cement.

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Table 4. Results of ANOVA for Compressive Strength Test

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LatCont	3	140.38844	46.79615	65.17	<.0001
VaCont	3	803.44649	267.81550	372.99	<.0001
LatCont*VaCont	9	127.76059	14.19562	19.77	<.0001
CuringAge	5	13543.90976	2708.78195	3772.57	<.0001
LatCont*CuringAge	15	137.83094	9.18873	12.80	<.0001
VaCont*CuringAge	15	23.17288	1.54486	2.15	0.0093
LatCon*VaCont*Curing	45	53.24587	1.18324	1.65	0.0112
Error	192	137.86000	0.71802		

Table 5. Duncan's Multiple Range Test for Compressive Strength with Varying VA Content

Duncan Grouping	Mean	N	VA Cont
A	20.4000	72	0
B	18.3208	72	10
C	17.1431	72	20
D	15.8597	72	30

Table 6. Duncan's Multiple Range Test for Compressive Strength with Varying LAT Content

Duncan Grouping	Mean	N	LAT Cont
A	19.1236	72	0
B	17.7139	72	20
C	17.4889	72	10
C	17.3972	72	30

Table 7. Duncan's Multiple Range Test for Compressive Strength with Varying Curing Age

Duncan Grouping	Mean	N	VA Cont
A	24.7688	48	120
B	24.1583	48	90
C	21.8229	48	56
D	19.7292	48	28
E	9.6396	48	7
F	7.4667	48	3

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